Abstract

Solar Probe Mission and System Design Concepts

James E. Randolph
NASA Space Physics Division

Major evolutionary steps have occurred recently in the design of the Solar Probe mission that have resulted in a new lightweight and low cost concept that will change the earlier perceptions of this scientifically exciting mission. NASA program guidelines emphasize low ifee-cycle-cost including the launch vehicle and mission operations costs. The new Solar Probe concept reflects these guidelines and is consistent with a realistic life-cycle cost of less than three hundred million dollars. This has been possible with the inheritance of high technology and low cost systems that have been developed for missions during the past decade. In addition, a significant reduction in the size of the Solar Probe scientific instruments have led to an accommodation of this miniaturized payload on the smaller spacecraft. New mission design concepts have optimized the encounter (perihelion) trajectory conditions allowing a new parabolic shield concept as discussed below. The perihelion radius is specified at four solar radii to capture as many of the scientific objectives consistent with the thermal environmental constraints. A polar orbit was chosen to allow measurements over the polar regions which are of significant scientific interest. Also, this mbit provides the maximum spacecraft separation from the Sun as seen from the Earth to optimize real-time telecommunications at Perihelion, Another geometry imperative is the orthogonality between the Earth--spacecraft line and the orbital plane at perihelion. This allows continuous nadir pointing of the thermal shield while minimizing the pointing requirements of a high gain antenna for real-time telecommunications. This orthogonally enables a major design breakthrough for the Solar Probe--a parabolic shield combining a thermal shield and a high gain antenna. The trajectory with these Perihelion conditions relies on Jupiter to provide the major source of energy for the final orbit. A direct launch to Jupiter followed by a Jupiter gravity assist maneuver enables the shortest flight time and lowest operations' costs, High launch energies are necessary for the direct trajectory due to the high approach velocities required at Jupiter leading to the final orbit toward the sun. With the new low mass concept for *the* Solar *Robe,* a small launch vehicle such as a Delta can provide the requital launch energy. System design concepts consistent with these mission requirements include small and low cost system elements. Unless the spacecraft can be made very small, launch vehicle (and associated propulsive stage) costs can be much greater than the spacecraft and payload costs combined. A small lightweight scientific payload will reduce the overall mass and allow payload accommodation on a small bus structure. This payload will satisfy a large fraction of the fundamental scientific objectives identified during earlier Solar Probe studies with larger payloads. The instrumentation will be fixed to the spacecraft bus with no articulation provided by the spacecraft in an effort to reduce the cost and complexity of the three axis stabilized attitude control system, The instruments will be mounted on a lightweight composite bus structure that must also support the large heat shield during launch. A lightweight, high strength, and refractory material is the basis for the primary heat shield that must tolerate almost three thousand suns of thermal flux at perihelion, Refractory metals have been rejected because of their high density and brittleness in favor of a carbon-carbon composite material that appears to have the requisite density and thermal properties. Surface coatings on the carbon-carbon were rejected because of expected ultraviolet degradation near perihelion and bonding concerns in this extreme thermal environment. Secondary shields will be used beneath the primary shield to reduce the temperatures in the busby almost an order of magnitude allowing the components in the shadow or umbra of the shield to operate near room temperature at perihelion. Carbon-carbon composites are recent developments promising to have the properties required for the primary shield, Confirmation of the optical properties of the surface of the carbon-carbon composites are underway with some high temperature

materials tests at the CNRS solar furnace at Odeillo-Font Romeu in France. The fundamental design goal of the shield is not simply survival at perihelion but to minimize the operating temperature and thereby minimize the sublimation from the shield. A sublimation specification of about three milligrams per second at perihelion will protect the Instruments that measure natural plasmas from the plasma that could rc.suit from excessive sublimation from the shield. Another key technology issue for the Solar Probe is telecommunications, Coronal perturbations on a radio signal are well known and can be minimized with higher frequency carriers. In order to minimize costs while using the highest available frequency, an X-bred system compatible with NASA's deep space network will be used, The thermal shield will have a parabolic shape such that the "back side" of the parabola w-ill face the Sun while the front side will act as a high gain antenna facing the Earth to minimize the amount of power required to provide real-time telemetry at perihelion. Spacecraft power is minimized by the parabolic shield concept and will be supplied by a single radioisotope thermoelectric generator to assure solar independent power over the extreme distances relative to the sun that are inherent in a Solar Probe mission. This technique provides the lowest mass and lowest risk alternative for a stable power source near perihelion, The lifetime radiation dose from this small power generator is much less than the dose caused by the high energy particle radiation during the Jupiter flyby. In addition, this power source does not require solar pointing for power during the mission simplifying the attitude control system. Celestial references will be used for attitude control during the long cruise duration of about 4 years while inertial references will be used during the perihelion passage to protect against any dust or particulate environment that might perturb a celestial sensor, Other electronics on board the spacecraft include a high performance central computer that is very lightweight and consumes low power. Also, a solid state data storage system that is lightweight and has very low power consumption will be flown. This data storage capability will be used as a redundancy to the real-time telemetry link at perihelion and for recording telemetry *when* no ground station tracking is available away from perihelion. These low mass and low power components in the current Solar Probe design produce a new inexpensive spacecraft and mission that will utilize a small launch vehicle and provide a low cost but exciting scientific return for this first exploratory mission to the sun.